ATTORNEY DOCKET: LI 2 RE #5

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Li et al.

Serial No.: 10/086,222
Filing Date: 02/27/2002
Title: HIGH PERFORMANCE SINGLE MODE WAVEGUIDE

PETITION FOR FILING PATENT APPLICATION BY THE ASSIGNEE

Group Art Unit: 2874
Examiner: TBA

Assistant Commissioner for Patents
Washington, DC 20231

Dear Sir:

Applicants, Corning Incorporated, hereby petitions the Commissioner to accept the filing of the above-identified U.S. Patent Application by it, as the party to which the invention disclosed and claimed in said Patent Application rightfully belongs, and on behalf of and as agent for the inventor.

An affidavit is attached hereto providing proof of the pertinent facts concerning the refusal of the inventor to join in the present application for patent and establishing that Corning Incorporated has a sufficient proprietary interest in this matter to make application on behalf of and as agent for the inventor, and showing that such action is necessary to preserve the rights of the parties and to prevent irreparable damage.

The name and address of the inventor refusing to join in this application is as follows:

Yanming Liu
3 Granger Pond Way
Lexington, MA 02420

The invention was developed under the authorization of Corning Incorporated by four inventors, one of whom was Yanming Liu, who was employed by Corning Incorporated to do so.

Upon information and belief, based on the precedent which will be discussed below, Corning Incorporated is entitled to clear title to the invention and to the above-identified patent application and any patent which issues thereon.

The Supreme Court of the United States in *Solomons v. United States*, 137 U.S. 342, 346 (1890) held:

> If one is employed to devise or perfect an instrument, or a means for accomplishing a prescribed result, he cannot, after successfully accomplishing the work for which he was employed, plead title thereto as against his employer. That which he has been employed and paid to accomplish become, when accomplished, the property of his employer. Whatever rights as an individual he may have had in and to his inventive powers, and that which they are able to accomplish, he has sold in advance to his employer.

It is clear that an employee who is paid to develop an invention comes within the scope of the language cited. Furthermore, Yanming Liu agreed to assign any and all patent rights to Corning Incorporated as a condition of his employment. A copy of the Agreement signed by Yanming Liu is attached to Exhibit A enclosed herewith.

Since Yanming Liu was employed by Corning Incorporated, that is, paid compensation to develop a broadband access fiber, this invention belongs to Corning Incorporated and the inventor who contributed to the development of the device has a duty to assign the invention, patent application and any patent which issues thereon to Corning Incorporated and upon direction of Corning Incorporated execute an application therefor.

Yanming Liu has left the employ of Corning Incorporated and refuses to execute the papers required for filing the present patent application. In particular, on March 5, 2002, a copy of the Assignment and Declaration papers were mailed to Yanming Liu and Yanming Liu was asked to sign these papers (Exhibit B). On May 17, 2002, Yanming Liu sent an e-mail (Exhibit C) to the undersigned Patent Attorney, which indicated that once Corning agreed to compensate Yanming Liu appropriately, he would sign the documents. As evidenced by the Affidavit of Robert L. Carlson, when asked what this meant, Yanming Liu responded that he estimated it would take him 15 minutes per page to review the application and that he should be paid $300.00 per hour. Corning Incorporated later offered to pay Yanming Liu what it believes is a reasonable compensation, i.e., $65.00 per hour at 5 minutes per page to review the documents. $65.00 per hour corresponds to Yanming Liu's previous hourly rate when he was a scientist employed by Corning Incorporated. Yanming Liu refused this offer stating that this was "way too low".

Corning Incorporated is believed to be entitled to make such application on behalf of and as agent for the inventor pursuant to 37 C.F.R. 1.47(b).

Please charge the required fee under 37 C.F.R. § 1.17(h) to Corning Incorporated Deposit Account No. 03-3325.

Respectfully submitted,

DATE: April 3, 2003

Attorney for Assignee
Robert L. Carlson
Reg. No. 35,473
Corning Incorporated
SP-TI-3-1
Corning, NY 14831
(607) 974-3502

Date of Deposit: April , 2003

I hereby certify that this paper or fee is being deposited with the United States Postal Service under 37 CFR 1.10 on the date indicated above and is Addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231

Signature ____
Robert L. Carlson

ATTORNEY DOCKET: LI 2 RE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s):	Li et al.	**AFFIDAVIT OF ROBERT L. CARLSON**
Serial No.:	10/086,222	
Filing Date:	2/27/2002	Group Art Unit: 2874
Title:	HIGH PERFORMANCE SINGLE MODE WAVEGUIDE	Examiner: TBA

Assistant Commissioner for Patents
Washington, DC 20231

STATE OF NEW YORK
COUNTY OF STEUBEN

ROBERT L. CARLSON, being duly sworn, and having personal knowledge of the facts set forth herein, hereby deposes and says that:

1. I am employed as Division Patent Counsel at Corning Incorporated, of Corning, New York.

2. Together with three (3) other inventors, Yanming Liu of 3 Granger Pond Way, Lexington, MA 02420, developed a High Performance Single Mode Waveguide disclosed and claimed in the accompanying Patent Application.

3. Before the reissue patent application was completed and ready for execution, Yanming Liu left the employ of Corning Incorporated.

4. On May 17, 2002, Yanming Liu sent an e-mail to me (Exhibit C), indicating that once Corning agreed to compensate him appropriately, he would sign the Declaration and Assignment papers. On May 17, 2002, I telephoned Yanming Liu to discuss signing the Declaration and Assignment papers for United States Application No. 10/086,222. He stated that he would not be willing to sign the documents until he was properly compensated. When I asked him what he meant by that, he indicated that it would take him 15 minutes per page to review the application papers and that he should be paid $300.00 per hour.

5. Yanming Liu's estimated salary while employed by Corning Incorporated was $65.00 per hour.

6. On May 31, 2002 I called Yanming Liu and offered to compensate him at a rate of $65.00 per hour at 5 minutes per page. He said this amount was "way too low". When I asked him if that was his final answer, he said "yes". (Exhibit D)

Robert L. Carlson

Sworn to before me this
3rd day of April, 2003.

Notary Public

DIANA L. SILVERNAIL
Notary Public, State of New York
Steuben County No. 01SI4798033
Commission Expires June 30, 2003

Exhibit A

CORNING INCORPORATED

Employee Patent and Proprietary Information Agreement

Corning Incorporated:

In consideration of my employment in any capacity by Corning Incorporated (hereinafter called the Company) and of the salary or wages id or to be paid to me by the Company.

1. I hereby covenant and agree to disclose to the Company all inventions made or conceived by me (whether made solely by me or jointly th others) from the time of entering the Company's employ until I leave, (a) relating to or growing out of any business then being carried on or ing developed by the Company, or (b) which result from or are suggested by any work which I may do for or on behalf of the Company. said ventions to be and remain the sole and exclusive property of the Company or its nominees whether patented or not.

2. I further agree that, at the request of the Company, whether such request is made during or subsequent to such employment, I will, itirely at the expense of the Company and through Attorneys or Agents designated by it, make application for Letters Patent of the United States id any and all countries foreign thereto with respect to any or all of said inventions, forthwith assign all such applications to the Company and its iccessors and assigns, and furnish such assistance and do all things, including the signing of necessary papers, as may reasonably be required of e to aid in the preparation and prosecution of such patent applications.

3. I further agree that I will not, either during or subsequent to my employment, disclose in any manner whatsoever (except as my duties ; an employee of the Company may require) any Proprietary information obtained during my employment by the Company, nor display for any urpose whatsoever any drawing, letter, report, or other form of Proprietary information, or any copies or reproduction thereof, belonging to or ertaining to the Company without due written authorization from a responsible officer thereof.

4. I further agree that I will notify the Company in writing before I make any disclosure to the Company, or perform or cause to be erformed any work for or on behalf of the Company, which appears to threaten conflict with (a) rights I claim in any invention or idea (i) onceived by me or others prior to my employment or (ii) otherwise outside the scope of this agreement or (b) rights of others arising out of bligations incurred by me (i) prior to this agreement or (ii) otherwise outside the scope of this agreement. In the event of my failure to give notice nder the circumstances specified in (a) of the foregoing, the Company may assume that no conflicting invention or idea exists, and I agree that I vill make no claim against the Company with respect to the use of any such invention or idea in any work or the product of any work which I erform or cause to be performed for or on behalf of the Company.

This agreement shall be binding upon my heirs, executors, administrators, or other legal representatives or assigns.

I represent that except as stated immediately herebelow I have no agreements with, or obligations to, others in conflict with the foregoing.

In witness whereof I have hereunto set my hand at Corning, New York on this 30 day of August, 19 93.

Witness:

Nancy A. Cole

[signature]

Signature in Full

FORM NO. CPOO48 (REV. 7/89)

Corning Incorporated
Patent Department

SP-TI-3-1
Corning, NY 14831

t 607 974
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Exhibit B

March 5, 2002

Mr. Yanming Liu
3 Granger Pond Way
Lexington, MA 02420

Re: Reissue of U.S. Patent 6,031,956
Li 2-10-2-9 RE

Dear Yanming:

CORNING
Discovering Beyond Imagination

Enclosed please find Combined Declaration and Power of Attorney in connection with the referenced file, together with a copy of the Reissue application attached thereto.

Please review the same and sign and date the Declaration document on page 4 under signature of Inventor 202. A return envelope is enclosed for your convenience in returning the signed document to me. Your prompt return will be greatly appreciated.

Do not hesitate to call me if you have any questions with regard to this matter. My direct number is (607) 974-3502.

Very truly yours,

Robert L. Carlson
Patent Portfolio Manager
Optical Fiber

RLC/dls
Enclosures (2)

Exhibit C

Carlson, Robert L

From: YANMING LIU[SMTP:liuym@msn.com]
Sent: Friday, May 17, 2002 8:51 AM
To: carlsonrl@corning.com; chervenawj@corning.com
Subject: Patent Signiture

Robert L. Carlson
Patent Portfolio Manager
Optical Fiber

William Chervenak
Patent Agent

Dear Bob and Bill,

As I have told both of you, I agree to sign the "Combined Declaration ..." document with reference to "Reissue of US Patent 6,031,956" sent by Robert Carlson and Patent application entitled "BROADBAND ACCESS OPTIMIZED FIBER AND METHOD OF MAKING" sent me by William J. Chervenak. However, I need to review these documents carefully as required in the declaration.

As declared in the "COMBINED DECLARATION AND POWER OF ATTORNEY", "We have reviewed and understand the contents of the specification, including the claims, of the attached reissue application." "We believe ourselves to be the original, first, inventors of the subject matter...." In addition, in "DECLARATION IN ORIGINAL APPLICATION": "I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true." I need to review these documents carefully and thoroughly. If it is only a matter of an hour or so I will look over and sign it. However, there are more than 40 pages of current document need to be reviewed and unknown pages of related documents or subsequent documents may required to be reviewed also, it will take me substantially amount of work. I am seeking financial compensation regarding the work. Once you agree to compensate me appropriately, I will review the document, give your appropriate feedback and sigh the documents.

Please contact me 781-589-6688 or email to me liuym@msn.com if you should have any questions or concerns.

Sincerely,

Yanming Liu

Exhibit D

MEMO

TO: Yanming Liu File

FROM: Robert L. Carlson

DATE: May 31, 2002

RE: Compensation Issue

Today I had a telephone conference with Yanming Liu, and told him that Corning would be willing to compensate Yanming Liu at a reasonable hourly rate and for a reasonable time for him to review the documents and sign them. I asked Yanming what his yearly salary was, and he indicated that his base salary was $130,000 per year. I then divided by 50 weeks and 40 hours per week and told him that I would agree to an hourly rate of $65 per hour, and that this was fair because this would correspond to the hourly rate he was making when he was a scientist at Corning, and that we would allow him 5 minutes per page to review each application. He indicated he would not sign for this amount, and stated that "This is way too low." I asked him "Is this your final answer?" He said "Yes."

[54] HIGH PERFORMANCE SINGLE MODE WAVEGUIDE

[57] ABSTRACT

Disclosed is a single mode optical waveguide fiber having a segmented core design. In particular, the core comprises three segments, each having characteristic dimensions and refractive index profile. By proper choice of index profile in each segment, a waveguide fiber is made which has a mode field diameter of about 9.5, low, positive total dispersion over the operating window 1530 nm to 1565 nm as well as effective area greater than 60 μm^2.

HIGH PERFORMANCE SINGLE MODE WAVEGUIDE

This application is based upon the provisi nal application Ser. No. 60/065.845. filed Nov. 17. 1997. [pending,] and provisional application Ser. No. 60/075,012, filed Feb. 17, 1998 which we claim as the priority dates of this application.

BACKGROUND OF THE INVENTION

The invention relates to a single mode optical waveguide fiber having a segmented core design which provides for high performance in the operating window around 1550 nm. In particular, effective area is large, the zero dispersion wavelength is outside the operating window, and total dispersion is positive over the operating window.

A waveguide having large effective area reduces non-linear optical effects, including self phase modulation, four wave mixing, cross phase modulation, and non-linear scattering processes, which can cause degradation of signals in high power systems. In general, a mathematical description of these non-linear effects includes the ratio, P/A_{eff}, where P is optical power. For example, a non-linear optical effect usually follows an equation containing a term, $\exp[P \times L_{eff}/A_{eff}]$, where L_{eff} is effective length. Thus, an increase in A_{eff} produces a decrease in the non-linear contribution to the degradation of a light signal.

The requirement in the telecommunication industry for greater information capacity over long distances, without regenerators, has led to a reevaluation of single mode fiber index profile design.

The focus of this reevaluation has been to provide optical waveguides which:

reduce non-linear effects such as those noted above;

are optimized for the lower attenuation operating wavelength range around 1550 nm;

are compatible with optical amplifiers; and,

retain the desirable properties of optical waveguides such as high strength, fatigue resistance, and bend resistance.

A waveguide fiber, having at least two distinct refractive index segments was found to have sufficient flexibility to meet and exceed the criteria for a high performance waveguide fiber system. The genera of segmented core designs are disclosed in detail in U.S. Pat. No. 4.715.679, Bhagavatula. Species of the profiles disclosed in the '679 patent, having properties especially suited for particular high performance telecommunications systems, are disclosed in U.S. Pat. No. 5.483.612, Gallagher et al.(the '612 patent).

The present invention is yet another core index profile species, closely related to the profiles set forth in the '612 patent, which reduces non-linear effects and which is particularly suited to transmission of high power signals over long distances without regeneration. The definition of high power and long distance is meaningful only in the context of a particular telecommunication system wherein a bit rate, a bit error rate, a multiplexing scheme, and perhaps optical amplifiers are specified. There are additional factors, known to those skilled in the art, which have impact upon the meaning of high power and long distance. However, for most purposes, high power is an optical power greater than about 10 mw. For example, a long distance is one in which the distance between electronic regenerators can be in excess of 100 km.

Considering the Kerr non-linearities, i.e., self phase modulation, cross phase modulation and four wave mixing, the benefit of large A_{eff} can be shown from the equation for refractive index. The refractive index of silica based optical waveguide fiber is known to be non-linear with respect t the light electric field. The refractive index may be written as,

$$n=n_0+n_2P/A_{eff},$$

where n_0 is the linear refractive index, n_2 is the non-linear index coefficient, P is light power transmitted along the waveguide and A_{eff} is the effective area of the waveguide fiber. Because n_2 is a constant of the material, increase in A_{eff} is essentially the only means for reducing the non-linear contribution to the refractive index, thereby reducing the impact of Kerr type non-linearities.

Thus there is a need for an optical waveguide fiber designed to have a large effective area. The window of operation of greatest interest at this time is that near 1550 nm. In addition, to further minimize four wave mixing effects, the total dispersion does not pass through zero over the range of operating wavelengths. In fact, the total dispersion remains positive over the operating window so that self phase modulation may cancel with the linear dispersion, a configuration required in soliton communication systems.

Definitions

The following definitions are in accord with common usage in the art.

The radii of the segments of the core are defined in terms of the index of refraction. A particular region has a first and a last refractive index point. The radius from the waveguide centerline to the location of this first refractive index point is the inner radius of the core region or segment. Likewise, the radius from the waveguide centerline to the location of the last refractive index point is the outer radius of the core segment.

Unless specifically noted otherwise in the text, the radii of the index profile segments discussed here are conveniently defined as follows, where the reference is to a chart of Δ% vs waveguide radius:

radius of the central core segment is measured from the axial centerline of the waveguide to the intersection of the extrapolated central index profile with the x axis;

radius of the second annular segment is measured from the axial centerline of the waveguide to the center of the baseline of the second annulus;

the width of the second annular region is the distance between parallel lines drawn from the half maximum refractive index points of the index profile to the x axis; and,

radius of the first annular segment is measured from the axial centerline of the waveguide to the first half maximum point of the second annular segment.

The effective area is

$$A_{eff}=2\pi(?E^2\, r\, dr)^2/(?E^4\, r\, dr),$$

where the integration limits are 0 to ∞, and E is the electric field associated with the propagated light. An effective diameter,

D_{eff} may be defined as,

$$A_{eff}=\pi(D_{eff}/2)^2.$$

The relative index, Δ%, is defined by the equation,

$$\Delta\%\ 100\times(n_1^2-n_2^2)/2n_1^2,$$

where n_1 is the maximum refractive index of the index profile segment 1, and n_2 is the refractive index in the

reference region which is usually taken to be the minimum index of the clad layer.

For the particular segmented profile described in this application, the first segment and the second annular segment Δ% will refer to the maximum relative index of the segments. The Δ% f the first annular segment will refer to the minimum relative index of that segment.

The term refractive index profile or simply index profile is the relation between Δ% or refractive index and radius over a selected portion of the core. The term alpha profile refers to a refractive index profile which follows the equation,

$$n(r)=n_0(1-\Delta|r/a|^{\alpha})$$

where r is core radius, Δ is defined above, a is the last point in the profile, r is chosen to be zero at the first point of the profile, and α is an exponent which defines the profile shape. Other index profiles include a step index, a trapezoidal index and a rounded step index, in which the rounding is due to dopant diffusion in regions of rapid refractive index change.

The profile volume is defined as $2?_{r1}^{r2}$ (Δ% r dr). The inner profile volume extends from the waveguide centerline, r=0, to the crossover radius. The outer profile volume extends from the cross over radius to the last point of the core. The units of the profile volume are % μm^2 because relative index is dimensionless.

The crossover radius is found from the dependence of power distribution in the signal as signal wavelength changes. Over the inner volume, signal power decreases as wavelength increases. Over the outer volume, signal power increases as wavelength increases.

Total dispersion is defined as the algebraic sum of waveguide dispersion and material dispersion. Total dispersion is sometimes called chromatic dispersion in the art. The units of total dispersion are ps/nm-km.

The bend resistance of a waveguide fiber is expressed as induced attenuation under prescribed test conditions. A bend test referenced herein is the pin array bend test which is used to compare relative resistance of waveguide fiber to bending. To perform this test, attenuation loss is measured for a waveguide fiber with essentially no induced bending loss. The waveguide fiber is then woven about the pin array and attenuation again measured. The loss induced by bending is the difference between the two measured attenuations. The pin array is a set of ten cylindrical pins arranged in a single row and held in a fixed vertical position on a flat surface. The pin spacing is 5 mm, center to center. The pin diameter is 0.67 mm. During testing, sufficient tension is applied to make the waveguide fiber conform to a portion of the pin surface.

Another bend test referenced herein the lateral load test. In this test a prescribed length of waveguide fiber is placed between two flat plates. A #70 wire mesh is attached to one of the plates. A known length of waveguide fiber is sandwiched between the plates and a reference attenuation is established by pressing the plates together with a force of 30 newtons. A 70 newton force is then applied to the plates and the induced attenuation in dB/m is measured.

SUMMARY OF THE INVENTION

The present invention meets a unique set of requirements for a class of high performance telecommunication systems by providing:

low total dispersion over a preselected wavelength operating range;

low attenuation at 1550 nm;

large effective area;

large mode field diameter;

a zero dispersion wavelength outside the range of operating wavelengths; and

acceptable bend performance.

A first aspect of the invention is a single mode optical waveguide fiber having a core region and a clad layer. The core region comprises three segments:

a circular central segment centered on the waveguide long axis;

a first annular segment surrounding the central segment; and

a second annular segment surrounding the first annular segment.

Each segment has a radius, drawn from the waveguide centerline, as defined above, a Δ%, and a refractive index profile. The second annular segment is also conveniently described in terms of a segment width. In this application Δ% is always referenced to the minimum clad index n_c.

This first aspect further has an a profile in over the circular central segment in which a in the range of about 0.7 to 2.0. The first annular segment is substantially flat, meaning that at the inner and outer extreme of the segment the refractive index may turn up or down. Also the first annular segment may have a low positive or negative slope without these deviations from flatness causing unacceptable change in the waveguide properties.

The relative index of the central segment, Δ_0% is greater than either the relative index of the first or second annular segments, Δ_1% and Δ_2%, respectively, and $\Delta_2\%>\Delta_1\%$.

The profile is further defined by the inner and outer profile volume and the ratio of outer to inner volume. Thus, inner volume is in the range 2.28 to 3.26% μm^2, the outer profile volume is in the range 3.70 to 13.75% μm^2, and the ratio of outer to inner volume is in the range 1.5 to 4.3.

In a preferred embodiment, which Δ_0% is in the range 1.01% to 1.35%, Δ_1% is in the range 0.03% to 0.21%, and Δ_2% is in the range 0.12% to 0.61% %. The Δ_0% is the modeled value of the α profile before centerline diffusion of the dopant. Diffusion will reduce this relative index value. For example, in the case of a triangular profile, one in which α=1, the value of Δ_0 is reduced by an amount in the range of 0.2% to 0.3% when diffusion is taken into account. For convenience, all of the Δ_0% values set forth in this specification and in the claims are the relative index values prior to diffusion. The respective radii ranges of the first two segments beginning at the central segment are r_0 in the range 2.06 μm to 2.80 μm, r_1 in the range 4.55 μm to 8.94 μm, and the width of the second annular segment is w_2 in the range 0.01 μm to 2.0 μm.

A refractive index indentation or indent may be present on the waveguide centerline. The indent is at least partially due to diffusion of the dopant species during process steps following deposition of the dopant glass and the base glass. Process steps may be taken to alter, reduce or remove this indent. However, profile modeling and manufacture of developmental waveguides have shown that an indent on center may exist without effecting waveguide performance. In particular, the central profile may have a refractive index indent at the center of the circular segment, the index indent having the approximate shape of an inverted cone, the indent having a minimum relative index in the range of about 0.5% to 0.7% and the radius of the base of the inverted cone shape is no greater than about 0.7 μm.

The waveguide made in accordance with this first aspect has the advantageous properties, total dispersi n over the

wavelength range 1530 nm to 1565 nm positive and no greater than 6.5 ps/nm-km, effective area not less than 60 μm^2, and mode field diameter in the range of 9 µm to 10 µm.

These properties are realized while maintaining cutoff wavelength, measured on waveguide fiber which has been placed in cable form, less than 1470 nm, attenuation at 1550 nm less than 0.22 dB/km, the induced loss under pin array bend testing less than 16 dB, and induced loss under lateral load bend testing less than 0.8 dB/m.

In a second aspect of the invention, the core segment profiles are limited as shown in Table 1 below to provide a set of operating parameters somewhat different from those of the first aspect of the invention. The additional limitations and the resulting change in waveguide parameters are put in place to satisfy an in use requirement, provide for ease of manufacture, for example, by making the waveguide less sensitive to manufacturing variances, or to reduce manufacturing cost.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a chart of refractive index profile, i.e., a chart of Δ% vs. waveguide radius for an idealized profile in accord with the invention.

FIG. 2 shows a measurement of Δ% vs. waveguide radius on a typical waveguide made in accord with the invention.

DETAILS OF THE INVENTION

The use of high performance optical waveguide fiber in the operating window near 1550 nm has greatly increased system capacity while keeping system cost reasonably low. The operating window in the range of about 1530 nm to 1565 nm is of particular interest because this wavelength range is characterized by low waveguide attenuation and is coincident with the bandwidth window of erbium doped waveguide fiber amplifiers.

What has been accomplished in the invention described herein, is the identification of a set of segmented core profiles which meet the requirements of a particular high performance telecommunications system. Further, the requirement set is met without increasing attenuation, while maintaining residual internal waveguide stress relatively low, and while maintaining acceptable bend performance.

The three core segments are indicated as 2, 6, and 8 in FIG. 1. In each segment, the shape of the index profile may take a general shape depending upon radial position. Also the radial extent of each segment may be changed.

As illustration of the definitions given above, the radius of central core region 2 is shown as length 4. In this application the central core radius is measured from the axial centerline to the intersection of the extrapolated central profile with the x axis.

The first annular segment 6 is delimited by the radius 4 and the radius 7, which extends to vertical line 5 drawn from the half index point of the second annular region. The first annular segment has a radius given by radius 7. The characteristic radius of the second annular segment 8 is radius 12, which extends from the core center to the midpoint of the base of segment 8, as indicated by point 3. This convention for second annulus radius is used in all modeled cases. A convenient profile measure for symmetrical profiles is the width 10 shown between vertical lines 5. Lines 5 depend from the half-maximum % delta index points. This convention for second annulus width is used in all modeled cases.

The cross over radius is shown as length 14 in FIG. 1. The profile volume, in units of % delta-microns^2, inside the cross over radius is the inner profile volume. The profile volume outside the cross over radius is the outer pr file volume. The outer to inner volume ratio is a measure of the relative power distribution at a given wavelength and thus is a measure f the effect of a particular index profile change.

An actual profile made in accord with the invention is shown in FIG. 2. Here the central segment comprises an indent portion 16 and an α profile portion 18. The α for the central segment refractive index profile 18 is essentially 1. The narrowness of this central segment is believed to be essential in achieving the required waveguide parameters, especially the increased effective area as compared to other dispersion shifted waveguide designs. Note that the relative index of the first annular segment 20 is greater than about 0.1 in this example. It is believed that a Δ_1% greater than or equal to 0.1 improves attenuation by reducing draw induced defects by reducing glass viscosity mismatch between the central segment and first annular segment during the drawing process. In addition, it is likely that this higher relative index improves bend resistance.

The position, peak value and shape of second annular segment 22, provides for confinement of the propagated light signal and thus maintains acceptable bend performance of the novel waveguide. The remarkable properties of the novel waveguide are given by the modeled results in Table 1.

TABLE 1

Waveguide Parameter	Embodiment 1	Embodiment 2
1530 nm Tot. Dispers. (ps · nm-km)	>1	>0.08
1565 nm Tot. Dispers. (ps · nm-km)	<5.5	<6.5
Mode Field Diameter µm	9–10	9–10
Cutoff (cabled) nm	<1360	<1470
Pin Array Bend dB	<16	<16
Lateral Load Bend dB/m	<0.8	<0.8
Att. @ 1550 nm (dB/km)	<0.22	<0.22

Table 2 shows the refractive index structure that provides the waveguide characteristics of Table. 1.

TABLE 2

Profile Parameter	Embodiment 1	Embodiment 2
Δ_0 % (maximum)	1.11–1.35	1.01–1.35
Δ_1 % (minimum)	0.03–0.14	0.03–0.21
Δ_2 % (maximum)	0.12–0.50	0.12–0.61
r_0 µm	2.06–2.45	2.06–2.80
r_2 µm	4.55–6.29	4.55–8.94
w_2 µm	0.7–2.0	0.01–2.0
Inner Volume % μm^2	2.28–3.00	2.28–3.26
Outer Volume % μm^2	3.70–8.12	3.70–13.75
Ratio-Outer/Inner	1.5–2.9	1.5–4.3

Note that in cases in which higher cutoff wavelength can be tolerated as well as a larger range of dispersion, one may use the wider ranges of embodiment 2. In some uses, the superior properties of embodiment 1 with respect to dispersion may be required. The tables serve to show the sensitivity of the waveguide properties to the profile structure.

It will be understood by those skilled in the art that alternative profile shapes, including step index and trapezoidal index may be used in the three segments in numerous combinations to provide the parameters set forth in Table 1.

Although particular embodiments of the invention have herein been disclosed and described the invention is n netheless limited only by the following claims.

We claim:

1. A single mode optical waveguide fiber comprising:

a core glass region comprising a first circular central segment, having a relative index $\Delta_0\%$ and a radius r_0, a first annular segment surrounding and in contact with the central segment, having a relative index $\Delta_1\%$ and a radius r_1, and a second annular segment surrounding and in contact with the first annular segment, having a relative index $\Delta_2\%$, a radius r_2, and a width w_2, the respective segments each having a refractive index profile;

a clad glass layer having a refractive index profile and a minimum refractive index n_c, wherein n_c is the reference index for the relative index of each core segment;

in which the index profile of the central segment is an a profile having α in the range of about 0.7 to 2, the index profile of the first annular segment is substantially flat, the index profile of the second annular segment is a rounded step, and $\Delta_0\%>\Delta_2\%>\Delta_1\%$,

the values of the respective Δ's and radii being chosen so that the inner profile volume is in the range 2.28 to 3.26% μm^2, the outer profile volume is in the range 3.70 to 13.75% μm^2 and the ratio of outer to inner volume is in the range 1.5 to 4.3.

2. The single mode waveguide of claim 1 in which $\Delta_0\%$ is in the range 1.01% to 1.35%, $\Delta_1\%$ is in the range 0.03% to 0.21%, and $\Delta_2\%$ is in the range 0.12% to 0.61%.

3. The single mode waveguide of claim 2 in which r_0 is in the range 2.06 μm to 2.80 μm, r_1 is in the range 4.55 μm to 8.94 μm, and w_2 is in the range 0.01 μm to 2.0 μm.

4. The single mode waveguide of claim 1 in which the circular central segment has a refractive index indent at the center of the circular segment, the index indent having the approximate shape of an inverted cone, the indent having a minimum relative index in the range of about 0.5% to 0.7% and the radius of the base of the inverted cone shape is no greater than about 0.7 μm.

5. The single mode waveguide of claim 1 in which the total dispersion over the wavelength range 1530 nm to 1565 nm is positive and no greater than 6.5 ps/nm-km, the effective area is not less than 60 μm^2, and mode field diameter is in the range of 9 μm to 10 μm.

6. The single mode waveguide of claim 5 in which the cut off wavelength measured on waveguide fiber which has been placed in cable form is less than 1470 nm, the attenuation at 1550 nm is less than 0.22 dB/km, the induced loss under pin array bend testing is less than 16 dB and the induced loss under lateral load bend testing is less than 0.8 dB/m.

7. A single mode optical waveguide fiber comprising:

a core glass region comprising a first circular central segment, having a relative index $\Delta_0\%$ and a radius r_0, a first annular segment surrounding and in contact with the central segment, having a relative index $\Delta_1\%$ and a radius r_1, and a second annular segment surrounding and in contact with the first annular segment, having a relative index $\Delta_2\%$, a radius r_2, and a width w_2, the respective segments each having a refractive index profile;

a clad glass layer having a refractive index profile and a minimum refractive index n_c, wherein n_c is the reference index for the relative index of each core segment;

in which the index profile of the central segment is an a profile having α about equal to 1, the index profile of the first annular segment is substantially flat, the index profile of the second annular segment is a rounded step, and $\Delta_0\%>\Delta_2\%>\Delta_1\%$, and,

$\Delta_0\%$ is in the range 1.11% to 1.35%, $\Delta_1\%$ is in the range 0.03% to 0.14%, and $\Delta_2\%$ is in the range 0.12% to 0.50%, and,

r_0 is in the range 2.06 μm to 2.45 μm, r_1 is in the range 4.55 μm to 6.29 μm, and w_2 is in the range 0.7 μm to 2.0 μm, and

the inner profile volume is in the range 2.28 to 3.00% μm^2, the outer profile volume is in the range 3.70 to 8.12% μm^2, and the ratio of outer to inner volume is in the range 1.5 to 2.9.

8. The single mode waveguide of claim 7 in which the circular central segment has a refractive index indent at the center of the circular segment, the index indent having the approximate shape of an inverted cone, the indent having a minimum relative index in the range of about 0.5% to 0.7% and the radius of the base of the inverted cone shape is no greater than about 0.7 μm.

9. A single mode optical waveguide fiber comprising a core region having a central segment having index of refraction Δ_0, a first annular segment having index of refraction Δ_1, and a second annular segment having index of refraction Δ_2, wherein Δ_0 is greater than either Δ_1 or Δ_2, the refractive index profile of the fiber tailored to result in said fiber exhibiting the following properties:

a zero dispersion wavelength outside the wavelength region 1530-1565 nm;

an effective area of at least 60 μm^2;

a cable cutoff wavelength less than about 1470 nm; and

a mode field diameter in the range of 9 μm to 10 μm.

10. The single mode fiber of claim 9, wherein said fiber exhibits positive dispersion over the wavelength region 1530-1565 nm.

11. The single mode fiber of claim 9, wherein said central segment comprises an α profile segment in which α is in the range of 0.7 to 2.0.

12. The single mode fiber of claim 10, wherein said central segment comprises an α profile segment in which α is in the range of 0.7 to 2.0.

13. The single mode waveguide fiber of claim 9, further comprising an attenuation at 1550 μm which is less than 0.22 dB/km.

14. The single mode waveguide fiber of claim 10, further comprising an attenuation at 1550 μm which is less than 0.22 dB/km.

15. The single mode waveguide fiber of claim 11, further comprising an attenuation at 1550 μm which is less than 0.22 dB/km.

16. The single mode waveguide fiber of claim 9, comprising an induced loss under pin array bend testing of less than 16 dB.

17. The single mode waveguide fiber of claim 10, comprising an induced loss under pin array bend testing of less than 16 dB.

18. The single mode waveguide fiber of claim 11, comprising an induced loss under pin array bend testing of less than 16 dB.

19. The single mode waveguide fiber of claim 13, comprising an induced loss under pin array bend testing of less than 16 dB.

20. The single mode waveguide fiber of claim 15, comprising an induced loss under lateral load testing of less than 0.8 dB/m.

21. The single mode waveguide fiber of claim 9, comprising a dispersion at 1530 nm which is greater than 1 ps/nm-km.

22. The single mode waveguide fiber of claim 11, comprising a dispersion at 1530 nm which is greater than 1 ps/nm-km.

23. The single mode waveguide fiber of claim 13, comprising a dispersion at 1530 nm which is greater than 1 ps/nm-km.

24. The single mode waveguide fiber of claim 15, comprising a dispersion at 1530 nm which is greater than 1 ps/nm-km.

25. The single mode waveguide fiber of claim 20, comprising a dispersion at 1530 nm which is greater than 1 ps/nm-km.

26. The single mode waveguide fiber of claim 9, wherein said fiber comprises a dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

27. The single mode waveguide fiber of claim 11, wherein said fiber comprises a dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

28. The single mode waveguide fiber of claim 13, wherein said fiber comprises a

dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

29. The single mode waveguide fiber of claim 15, wherein said fiber comprises a dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

30. The single mode waveguide fiber of claim 19, wherein said fiber comprises a dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

31. The single mode waveguide fiber of claim 25, wherein said fiber comprises a dispersion over the wavelength region 1530 nm to 1565 nm which is positive and no greater than 6.5 ps/nm-km.

32. The single mode waveguide fiber of claim 9, wherein said fiber exhibits a cable cutoff wavelength less than about 1360 nm.

33. The single mode waveguide fiber of claim 11, wherein said fiber exhibits a cable cutoff wavelength less than about 1360 nm.

34. The single mode waveguide fiber of claim 15, wherein said fiber exhibits a cable cutoff wavelength less than about 1360 nm.

35. The single mode waveguide fiber of claim 19, wherein said fiber exhibits a cable cutoff wavelength less than about 1360 nm.

36. The single mode waveguide fiber of claim 31, wherein said fiber exhibits a cable cutoff wavelength less than about 1360 nm.

FIG. 1

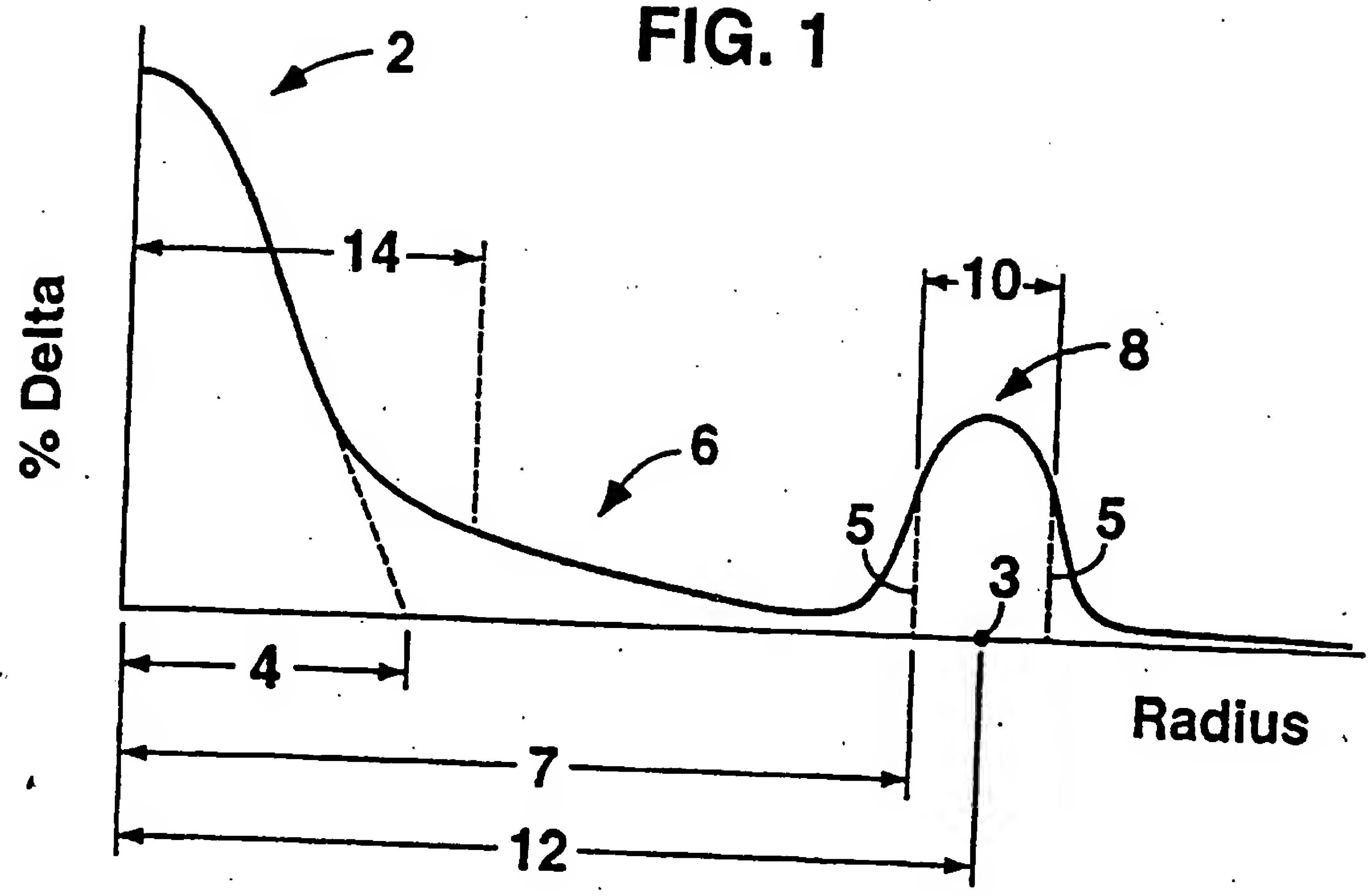

FIG. 2